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INFORMATION PROCESSING AS A FUNCTION OF
TASK PREDICTABILITY AND INTERDEPENDENCE

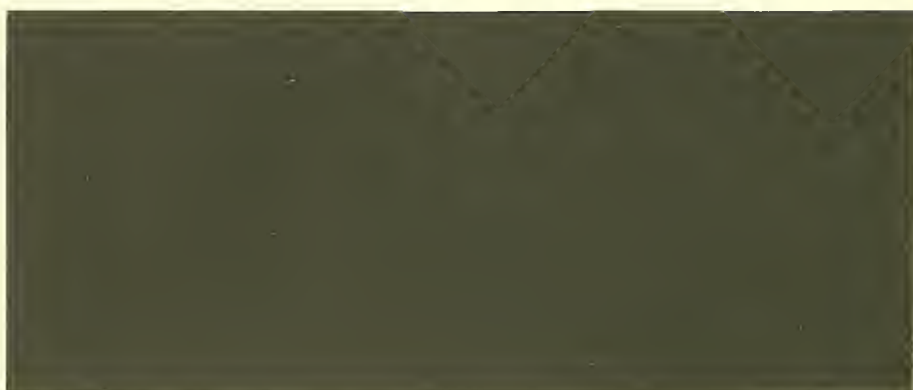
by

Jay R. Galbraith
Milton L. Lavin

December 1970

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INFORMATION PROCESSING AS A FUNCTION OF TASK PREDICTABILITY AND INTERDEPENDENCE

Jay R. Galbraith, Massachusetts Institute of Technology
Milton L. Lavin, Massachusetts Institute of Technology

A number of empirical studies done during the past decade suggest that task predictability is a primary determinant of information load, and thus, a key influence upon organizational form. In particular, the research of Burns and Stalker (1), Woodward (6), Hall (3), and Lawrence and Lorsch (5) all strongly support the importance of task predictability.

What is missing in this empirical research is an explanation of why uncertainty should affect organization forms. The models presented below give a partial explanation of why this is so. The basic explanation is that task uncertainty requires information processing during the execution of the task. The effect of uncertainty is hypothesized to be moderated by the interdependence between subtasks and the number of elements relevant for decision making (e.g. number of employees, number of specialties, etc.).

A survey of published theory and empirical research suggests an orderly organizational response to information load. This response can be characterized by a conceptual model which explains how a simple organization becomes more complex by employing successively more costly structural alternatives to cope with an increasing information load. Later in the paper, one particular alternative, organizational hierarchy, is developed into a normative model, and the paper is concluded with a brief report of current research on task coordination within a large manufacturing firm.

A Conceptual Model for Design:

The conceptual model is based on the assumption that, in order to be effective, the information processing capacity of an organization must be equal to the information processing requirements of the task. Consider a large organization with a highly interdependent set of activities. In addition, assume that the subtasks are differentiated and make use of functional specialization. The problem facing the organization is how to obtain an integrated pattern of behavior across all of the interdependent subunits. The magnitude of the integration problem depends on the amount of information that has to be processed in order to coordinate the interdependent subunits. In the situation just described, the amount of information varies with the uncertainty of the task. For purposes of exposition, assume that first the task is predictable and then increases in uncertainty.

The simplest method of coordinating interdependent departments is to specify the behaviors in advance of their execution. The organization's employees are taught the job related situations which they will face and the behaviors appropriate to those situations. If everyone adopts the specified behaviors, the resultant aggregate response is coordinated.

However, the use of rules is limited in the amount of complexity that can be handled. For tasks with multiple job related situations, the number

of rules necessary to coordinate interdependent behavior become too large to learn. At this point the formal hierarchy of authority is employed on an exception basis. That is, the recurring job situations are programmed with rules while the infrequent situations are referred to higher levels in the hierarchy.

As the uncertainty of the organization's task grows, coordination increasingly takes place by specifying outputs, goals, or targets. Instead of describing appropriate behaviors in detail, the organization undertakes processes for setting the goals to be achieved, and the employees select those behaviors which lead to goal accomplishment. Planning reduces the amount of information processing in the hierarchy by increasing the degree of discretion exercised at lower levels.

The ability of an organization to utilize coordination by planning, hierarchy, and rules, depends on the combination of the frequency of exceptions and the capacity of the hierarchy to handle them. As the number of exceptions begin to overload the hierarchy, the organization can take action either to reduce the amount of information required or to increase the capacity of the structure to process more information.

The information load can be reduced by adding slack resources, which in turn, reduce the amount of interdependence between subtasks. This strategy maintains a centralized decision making process as long as slack can be added to cope with increasing uncertainty. Another way to reduce the information load is to change the structure to a more self-contained form. This reduces the interdependence between subtasks while bringing the decision making power down to where the information exists. Therefore, this response results in decentralization.

One strategy for increasing information processing capacity is to reduce the time between successive planning sessions. This requires more information flowing to update the status of the files. The change occurs in the formal, sometimes mechanical, information system. It brings information up to the decision makers, and so, results in centralization of decisions. Using lateral relations between subunits is another way to increase capacity. This brings decision making lower in the organization, and thus, results in decentralization. Joint decision making is employed to permit decentralized management of strongly interdependent subtasks.

In reality, various combinations of these strategies will be used, depending upon the relative costs involved. In another paper (6), Galbraith describes a case study of an organization facing these design choices.

A Normative Model for Design:

A simple design model may be developed by holding all policy variables constant but the managerial hierarchy. Thus, in the model which follows, it is assumed that elemental tasks have been specified and task coordination costs have been measured. The problem is to specify a managerial hierarchy to handle a fixed amount of coordination at least supervisory cost. To choose among hierarchies having the same supervisory cost, it is required that the dollar cost of the time actually spent in coordination be minimal. The second order criterion frees time for higher

level managers to find and solve problems outside the pale of task coordination.

Let us begin by specifying model elements and certain intermediate quantities used in the analysis. Define

- n^α : the total number of tasks at the α th level in the hierarchy; $\alpha = 1$ denotes the lowest level.
- c_{ij}^α : one half of the personnel cost of coordinating tasks i and j at level α , measured in men; c_{jj}^α is the full cost of handling the nonroutine problem solving and administrative requests which involve task j alone; by construction, $c_{jj}^\alpha < 1$.
- \underline{x}_i^α : a vector of zeros and ones specifying which tasks are included in the i th group; e.g., x_{ij}^α is one if the j th task is in the i th group and is zero otherwise.
- s^α : the salary paid an α -level manager; it is assumed that $s^{\alpha+1} > s^\alpha$ for all α .
- z_i^α : the α -level contribution to the i th criterion in the objective function.
- \underline{z} : the lexicographic objective function, structured as ranked elements of a vector.

It is now a simple matter to pose the problem. For the sake of brevity, the explanation of each relation is postponed until all are assembled.

Specification of a hierarchy requires the selection of integers ($0 \leq x_{ij}^\alpha \leq 1$) to

$$\min_{\underline{z}_2} \left\{ \min_{\underline{z}_1} (\underline{z}) \right\} \quad 1)$$

where

$$\underline{z}_1^\alpha = \sum_{\alpha=1}^m s^\alpha \underline{e}^T [(A^\alpha * I) + I] \underline{e} \quad 2)$$

$$\underline{z}_2^\alpha = \sum_{\alpha=1}^m s^\alpha \underline{e}^T (A^\alpha * I) \underline{e} \quad 3)$$

$$A^\alpha = X^{\alpha T} C^\alpha X^\alpha \quad 4)$$

subject to constraints

$$(A^\alpha * I) \underline{e} \leq \underline{f}^\alpha \quad 5)$$

$$\left\{ ((C^\alpha + I) \#) * (X^\alpha X^{\alpha T}) - (X^\alpha X^{\alpha T}) \right\} = 0 \quad 6)$$

$$(X^\alpha \underline{e} - \underline{e}) = 0 \quad , \quad 7)$$

where I is the identity matrix, \underline{e} is a vector of ones, the symbol $(*)$ denotes element by element multiplication, $[u]$ is a truncation operator

yielding the largest integer smaller than u , m is the smallest value of α for which $C^{\alpha+1}$ is identically zero, the symbol $(\#)$ is a Boolean operator such that $u\#$ equals one if u is positive and is zero otherwise, and

$$f_i^\alpha = \max_{\substack{i=1, n^\alpha \\ j=1, n^\alpha}} \{ (x_i^\alpha - x_j^\alpha) * D^\alpha \} \quad (8)$$

$$d_{ij}^\alpha = d_{ji}^\alpha = \left[(c_{ii}^\alpha + c_{ij}^\alpha + c_{ji}^\alpha + c_{jj}^\alpha) + 1 \right]. \quad (9)$$

the coordination matrix for the next level is obtained from the relation

$$C^{\alpha+1} = (A^\alpha - A^\alpha * I). \quad (10)$$

Let us now examine each of the relations in the problem statement. The objective function is unusual because of its lexicographic character. It instructs one 1) to find the set of hierarchies requiring the least total supervisory cost, and then 2) to select from that set the hierarchies where the dollar cost of coordination is minimal. Note that other properties of the hierarchy may be incorporated into the objective function either as simple lower order criteria, or as weighted sums.

Equations 2) and 3) specify how the α -level contributes to each criterion. Supervisory cost z_1^α is merely α -salary times the number of men required to coordinate the α -level tasks, whereas, coordination cost z_2^α is the product of α -salary and the manpower actually spent in task coordination. The manpower components of z_2^α and z_1^α are, respectively, the actual and the "rounded-up" elements along the main diagonal of A^α .

The three constraints are easily described. Relations 5) 8), and 9) state that the coordination manpower required by a task group cannot exceed the whole number of individuals required to manage that pair of interdependent tasks which need more supervision, as a unit, than any other pair in the group. This condition permits the formation and efficient use of task forces, but at the same time it sharply limits task force size. The second constraint states that only interdependent tasks may be grouped together, and the third requires that each task must be a member of exactly one task group.

In the model developed above, coordination cost was assumed known. That model can be extended by specifying how shared resources and task precedence relations affect the total cost of a particular design (4).

Empirical Research on Task Coordination:

Because coordination effort is a key factor in the design of organizations, measurement of coordination was the logical next step in the development of theory. During the past four months the two authors have been studying coordination activity within a large manufacturer of communication equipment. The study was centered on two production shops, which we will call A and B, both making equipment to do the same communication job. However, A's product was a new design using new manufacturing technology. In fact, A's product is so new that the first deliveries occurred in mid-1970. In contrast, B's product has been on the market since 1963. Moreover, A had younger, less experienced employees, and was subject to higher turnover

than shop B. Thus, because of frequent engineering changes, machine breakdowns, and loss of trained personnel, we would characterize shop A as having a much less predictable task than B. Consequently, we would expect more vertical communication within B and more lateral communication both within A, and between A and other departments.

During each day of the second and fourth weeks of August 1970, managers in A and B reported both the number of job related contacts and the time spent with subordinates, boss, and other managers. These data partially support the prediction about differences in communication patterns. The eleven foremen of A spend about 11 minutes/day with their boss compared to the 28 minutes/day spent by the eight foremen of B. A Mann-Whitney U test for a difference in the ranked contact times yields a U of 10, corresponding to a one-tail p-level of 0.001. Moreover, the A foremen spend an average of 159 minutes/day with people at their level outside of A, whereas, the B foremen spend only 73 minutes/day in such contacts ($U = 14$, $p < 0.01$).

However, all the data do not support our predictions. A foremen do not spend significantly less time with their subordinates, do not have significantly more contact with other A foremen, and do not contact more functional specialties per day. In fact, A managers contact significantly fewer functions. Inexperienced personnel in A may help to explain the first disconfirming result and the other missed predictions may be related to large fluctuations in B's order flow. We are presently examining data on orders, quality defects, machine breakdowns, turnover, etc., and we hope eventually to refine the notion of task predictability by breaking it down into components.

Footnotes:

- (1) Burns, Thomas and Stalker, G.G., The Management of Innovation, Tavistock Publications, London, (1961).
- (2) Galbraith, Jay R., "Environmental and Technological Determinants of Organization Design: A Case Study", in Studies in Organization Design, edited by Paul Lawrence and Jay Lorsch, Irwin, Homewood, Illinois, (1970).
- (3) Hall, Richard H., "Intraorganizational Structural Variation: Application of the Bureaucratic Model", Administrative Science Quarterly, vol. 7, pp. 295-308, (1962).
- (4) Lavin, Milton L., "A Normative Model for Organization", Working Paper 454-70, Alfred P. Sloan School of Management, M.I.T., Cambridge, (1970).
- (5) Lawrence, Paul and Lorsch, Jay, Organization and Environment, Division of Research, Harvard Business School, Boston, (1967).
- (6) Woodward, Joan, Industrial Organization: Theory and Practice, Oxford University Press, London, (1961).

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